OPTICAL ISOLATOR WITH AlInAs-OXIDE CLADDING LAYER EMPLOYING NONRECIPROCAL RADIATION MODE CONVERSION

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Abstract

An optical isolator employing a nonreciprocal radiation mode conversion was studied. The optical isolator was comprised of a magnetic garnet / GaInAsP / InP waveguide. Selective oxidation of an AlInAs layer grown on an InP substrate was considered to enhance a magneto-optic effect in the optical isolator. The magneto-optic effect was calculated in the magneto-optic waveguide with a magnetic garnet / GaInAsP / AlInAs-oxide structure.

Introduction

Wafer direct bonding is an attractive technique for the integration of dissimilar materials without any adhesives [1,2]. The authors have applied this technique to the bonding between semiconductors and magneto-optic materials with the aim of integrating a laser diode and an optical isolator. Recently, the authors demonstrated a performance of an optical isolator employing a nonreciprocal phase shift, in which a magnetic garnet / GaInAsP / InP waveguide was constructed by wafer direct bonding technique [3]. By using a nonreciprocal phase shift, an optical isolator employing a nonreciprocal radiation mode conversion was proposed [4].

The authors considered that an optical isolator employing a nonreciprocal radiation mode conversion could be constructed with a magnetic garnet / GaInAsP / InP waveguide. Selective oxidation of an AlInAs layer grown on an InP substrate was also studied to enhance the magneto-optic effect. In this paper, the authors report on an optical isolator with a magnetic garnet / GaInAsP / InP (or AlInAs-oxide) waveguide employing a nonreciprocal radiation mode conversion.

Device structure

Figure 1 shows an integrated optical isolator, employing a nonreciprocal radiation mode conversion, fabricated by wafer direct bonding. A magnetic garnet cladding layer is connected with a GaInAsP guiding layer by wafer direct bonding. The nonreciprocal phase shift occurs in TM modes traveling in a magneto-optic waveguide where the magnetization is aligned transversely to the light propagation direction in film plane [3]. By adjusting waveguide parameters, propagation constants of TE-like and TM-like modes satisfy a following relationship:

$$\boldsymbol{b}^{y}_{11b} < \boldsymbol{b}^{x}_{c} < \boldsymbol{b}^{y}_{11f} \qquad (1)$$

where $\boldsymbol{b}^{y}_{11f}$, $\boldsymbol{b}^{y}_{11b}$ denote the propagation constants of forward and backward traveling TM-like waves, respectively, and $\boldsymbol{b}^{x}_{c}$ denotes the cutoff of a TE-like wave. In this case, only the backward traveling TM-like waves are coupled to the TE-like radiation waves.

The optical isolator with the magnetic garnet / GaInAsP / InP waveguide was designed at a wavelength of 1.55 μm. A broken line indicates calculated nonreciprocal phase shifts of the three-layered slab waveguide in Fig. 2. $(CeY)_3Fe_5O_{12}$ (Ce:YIG) [4] was considered as a magnetic garnet cladding layer. When the GaInAsP thickness is 0.44 μm, the nonreciprocal phase shift has its maximum. In Fig. 3, open and filled triangles show the waveguide parameters of the magneto-optic waveguide with a 0.44-μm-thick GaInAsP guiding layer to satisfy Eq. (1), that is, the device operates as an optical isolator. When the rib height is 59 nm, the rib width for the isolator operation ranges between 3.96 and 4.03 μm (with a tolerance of 70 nm).

The nonreciprocal phase shift is experienced by evanescent fields in the Ce:YIG upper cladding layer. The refractive index of Ce:YIG is lower than that of InP so that only a small amount of the electromagnetic field exists in the upper cladding layer. A large nonreciprocal phase shift is required to enlarge the difference between $\boldsymbol{b}^{y}_{11f}$ and $\boldsymbol{b}^{y}_{11b}$, which relaxes the condition of the waveguide parameters to satisfy Eq. (1).

Recently, selective oxidation of Al-bearing III-V heterostructure systems has been studied for various applications [5-7]. The authors applied this technique to construct a magnetic garnet / GaInAsP / AlInAs-oxide waveguide to enhance the magneto-optic effect.

Experimental results and simulation

An AlInAs layer with a thin InP cap layer was grown on an InP substrate by metal-organic vapor phase epitaxy. The AlInAs layer was oxidized at 500℃ under carrier N_2 gas bubbled through H_2O at 85°C [7]. Refractive indices of AlInAs and its oxide measured by spectroscopic ellipsometer are shown in Fig. 4. By the selective oxidation, the refractive index of AlInAs could be reduced.

The nonreciprocal phase shifts were calculated for waveguides with Ce:YIG / GaInAsP / AlInAs-oxide (or air) structure. As shown in Fig. 2, in cases of both AlInAs-oxide and air, the maximum nonreciprocal phase shifts were more than ten times larger than that of the waveguide with the Ce:YIG / GaInAsP / InP structure. The AlInAs-oxide cladding layer is effective for rigid support of the GaInAsP guiding layer compared with air. Open and filled circles in Fig. 3 show the parameters of the magneto-optic waveguide with a 0.40-μm-thick GaInAsP guiding layer for the isolator operation. The GaInAsP thickness was designed in consideration that the radiation loss to the InP substrate should be suppressed. When the rib height is 84 nm, the tolerance of the rib width for the isolator operation is approximately 180 nm, more than twice of that in the optical isolator with the Ce:YIG / GaInAsP / InP waveguide.

Fabrication of the optical isolator with the Ce:YIG / GaInAsP / AlInAs-oxide waveguide, which employs the nonreciprocal radiation mode conversion, is now in progress.

Conclusion

An integrated optical isolator employing a nonreciprocal radiation mode conversion was discussed. The optical isolator was comprised of a magneto-optic waveguide with a magnetic garnet / GaInAsP / InP structure. Selective oxidation of an AlInAs layer grown on an InP substrate was investigated to enhance the magneto-optic effect. The AlInAs-oxide cladding layer was effective for not only the enhancement of the nonreciprocal phase shift but also the rigid support of the GaInAsP guiding layer.

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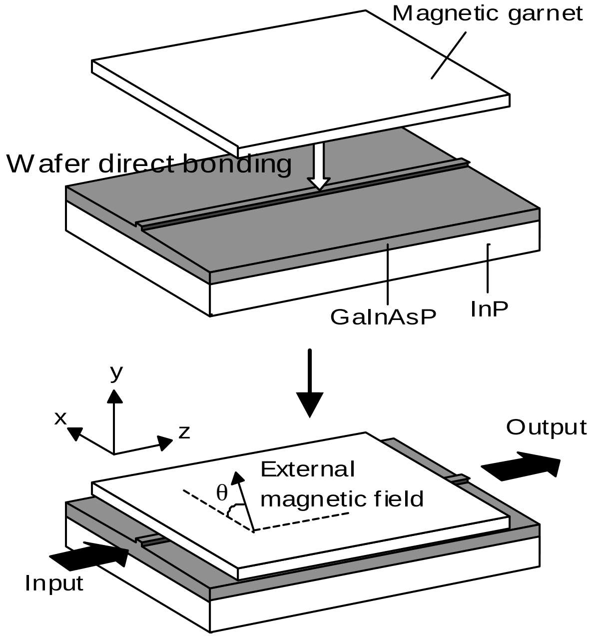

Fig. 1.Optical isolator with GaInAsP guiding layer employing nonreciprocal radiation mode conversion.

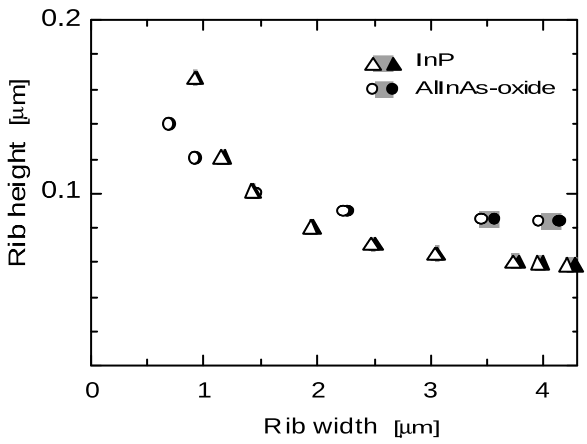

Fig. 3. Relationship between rib height and rib width for isolator operation.

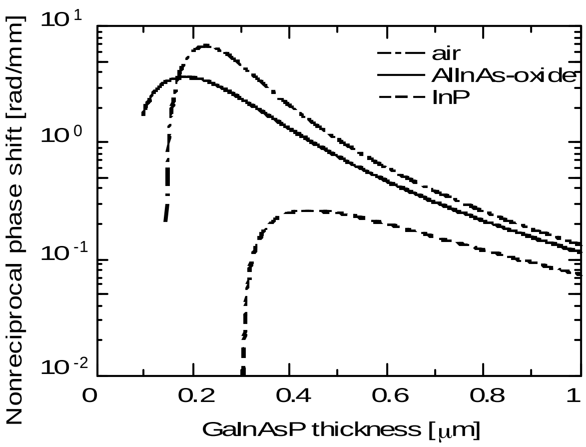

Fig. 2. Calculated nonreciprocal phase shifts of three-layered slab waveguides.

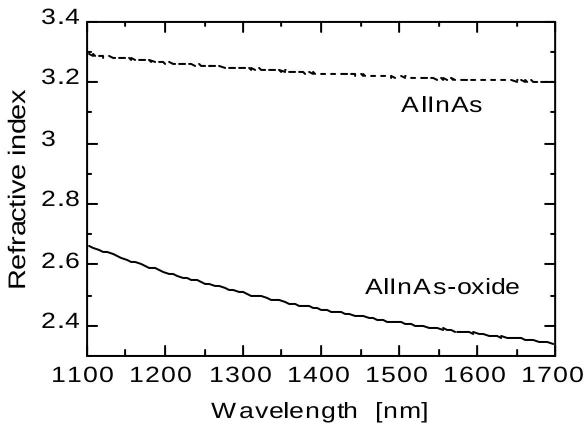

Fig. 4. Measured refractive indices of AlInAs and AlInAs-oxide.